

Kanuti NWR Progress Report FY03-03

**Small mammal community dynamics investigation for  
Mouse Lake, Kanuti National Wildlife Refuge 1993-2002**

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An investigation of small mammal dynamics has been conducted by U.S. Fish & Wildlife Service (USFWS) personnel of the Kanuti National Wildlife Refuge for the past 10 years to investigate small mammal dynamics following naturally occurring fires. This work has been conducted at "Mouse Lake" (66° 18.8' N x 151° 45.02' W) (Figure 1). The motivation, data collection methods, and interim results of these field investigations have been presented in a number of reports, most recently Saperstein (2002). The purpose of this report is to synthesize the data from captures of individuals in the field into an assessment of not only the abundance of the various species found during these investigations, but also to merge these data with individual weight dynamics to produce an overall assessment of the biomass dynamics of this group of primary consumers.

This group of organisms constitutes a prey base for a number of commercially valuable species, important to the subsistence resource users. Earlier investigations by researchers at another refuge in Interior Alaska (Paragi et al. 1996; Johnson et al. 1995 ) found the prey base for furbearers was substantially altered by fire disturbances to the ecosystem. Most significantly, the presence of colonial yellow-cheeked voles (*Microtus xanthognathus*) constituted a desirable source of prey for marten (*Martes americana*). The yellow-cheeked vole is considered an obligate species of fire disturbance in the boreal forest (Swanson 1993; Wolff and Lidicker 1980). Being large-bodied individuals, able to reach 150g in body weight (Lehmkuhl 2000), establishment of colonies of yellow-cheeked voles following fire should have profound influence upon the biomass of prey, and consequently upon the ability of an ecosystem to support populations of furbearers.

**Analytical methods**

Two phases of the analysis were conducted, and the results of the phases were combined to produce an overall assessment of small mammal community dynamics on the study plots established by USFWS staff. To facilitate analysis, and presentation of results, some species occurring on the study plots were

merged to give a clearer picture of the community dynamics. All of the 5 species of shrews detected over the course of the study were combined into a single category (*Sorex sp.*). Similarly, two species of lemmings (northern bog lemming (*Synaptomys borealis*) and brown lemming (*Lemmus trimuncronatus*)) were combined into a single group. Finally, 2 species of small-bodied voles of the genus *Microtus* (tundra vole *M. oeconomus* and meadow vole *M. pennsylvanicus*) were combined. The highly common northern red-backed vole (*Clethrionomys rutilus*) and yellow-cheeked vole were not merged with any other species, as they constituted a focus of the study.

An estimate of the biomass of each species group was obtained by first estimating the average mass of individuals captured on each grid in each year. The age distribution for a species will change annually dependent upon productivity and local conditions. In addition, measures of precision of average mass of a species group were produced by calculating the sample variance of the weighed individuals. This average individual mass was multiplied by the estimated number of individuals of that species on each plot in each year.

Computation of abundance on the grids followed the methods described in White et al. (1982:101-119). With the use of removal trapping, and 3 nights of trapping effort, the only estimator of population abundance, under the assumption of closure, is the removal estimator (Zippin 1956). The parameters of this model, for a 3 occasion experiment are  $\hat{p}$  and  $\hat{N}$  with a single degree of freedom remaining to assess fit of the model. Two criteria were employed for the 160 data sets (5 species groups • 4 grids • 8 years of data collection) available for analysis. First a minimum of 11 individuals of a species group needed to be captured on a particular grid. If that condition was satisfied, then the capture data was assessed using the depletion criterion presented by White et al. (1982:108):

$$\text{criterion} = \sum_{j=1}^t (t+1-2j)u_j > 0$$

where  $t$  is the number of sampling occasions (3 in this case), and  $u_j$  is the number of individuals captured on the  $j^{th}$  occasion. This simplifies, in the situation of 3 occasions to:

$$u_1 - u_3 > 0,$$

i.e., more individuals must be captured on the first sampling occasion than are caught on the last occasion. The amount by which captures on the first occasion exceed the number of captures on the last occasion has a substantial influence upon the bias and precision of the resulting estimates.

If a data set failed these criteria, the only recourse available to estimate the abundance of individuals on the grid is to use the minimum number known alive, or  $M_{t+1}$  in the notation of White et al. (1982). This estimate of abundance is suboptimal for 2 reasons: a) it is obviously biased low (particularly for a 3-occasion experiment, see Nichols and Pollock (1983)) and b) it amounts to an index rather than an estimate, and as such, possesses no measure of precision. Substitution of  $M_{t+1}$  in situations where abundance cannot be estimated has 2 consequences: a) estimates of biomass will be underestimated, and b) measures of precision

associated with population biomass will likewise be underestimated (because there will be no uncertainty associated with the estimate of abundance on the grid).

Upon computing the estimated abundance, and average individual mass for all grid•year•species group combinations available, a measure of precision of the resulting population biomass estimate was calculated using the variance of a product, described by Goodman (1960):

$$\text{var}(\text{population biomass}) \approx \hat{N}^2 \text{ var}(\text{average individual biomass}) + \text{average individual biomass}(\text{var}(\hat{N}^2))$$

Estimates of community biomass for all species groups represented on a grid in a given year were simply the sums of the estimated population biomass values. Measures of precision of community biomass estimates were calculated by recognizing that the variance of a sum is equal to the sum of the variances.

For comparison among habitats, community biomass estimates were averaged across years (1999–2002), and a delta method approximation to the precision of these derived estimates were calculated using

$$\text{var}(1999 - 2002 \text{ average}) = \frac{1}{4^2} \sum_{i=1}^4 \text{var}(\text{community biomass}_i)$$

Conceivably, a weighted mean (weighting the annual community biomass estimates by the inverse of their variances would have been preferable; however because of a unique set of circumstances coinciding on Grid 1 in 1999, no measure of precision was available for that estimate, negating the ability to employ the weighted average method.

To assess the magnitude of the precision estimates of abundance, a small simulation study was conducted looking at the effect of changing the number of sampling occasions. These simulations were performed using the analytical package WiSP (Wildlife survey simulation package) (Borchers et al. 2002). A population size of 100 with heterogeneous capture probabilities similar to that seen in the Mouse Lake populations was simulated and the magnitude of precision in these estimates was assessed using 200 realizations of 3-, 4-, and 5-occasion sampling schemes (see Appendix A).

## Results

Abundance estimates were possible for only 55 of the 160 grid•year•species group combinations, although a large fraction of situations for which estimation was not possible was because no individuals of that species group was captured during the 3 sampling occasions. The average coefficient of variation (CV) on the abundance estimates was 37.1%, whereas the average CV on the individual mass estimates was 25.5%. It then comes as no surprise that the average CV on the population biomass estimates is 51.4%, the greatest contribution to this uncertainty deriving from uncertainty in abundance.

Tables 1 and 2 present summaries of the individual mass and population abundance components of the population biomass estimates (presented in Table 3). Table 4 sums these species group-specific estimates into community-level biomass estimates and their measures of precision. Figure 2 is a graphical representation of the tabular material presented in Tables 3 and 4. Figure 3 is a graphical representation of the material presented in Table 1, showing the distribution of individual mass by the predominant species groups (*Clethrionomys rutilus*, lemmings, and *Microtus xanthognathus*). These graphs show the spread of individual masses, indicative of different age structures present in the sampled populations in differing years. Note, the annual sampling schedule attempted to visit the site at a consistent time of the snow-free season so that differences that appear are likely the consequence of differing mortality and recruitment processes operating through time.

Averaged over the period 1999-2002, estimated community biomass on the upland grids was Grid 1  $\bar{x} = 4520\text{g}$  (SE=511), Grid 2  $\bar{x} = 4175\text{ (SE=882)}$ , whereas on the tussock grids Grid 3  $\bar{x} = 5090\text{ (SE=1301)}$ , Grid 4  $\bar{x} = 6496\text{ (SE=1849)}$ . Tests of significance would not indicate an appreciable difference given the large uncertainty in these estimates, but the trend is for both tussock grids to be higher in community biomass than the upland grids.

The magnitude of uncertainty arising from abundance estimates (CV=37%) can be compared to the empirical measures of uncertainty shown in Figure 4. These 95% confidence intervals are asymmetrical so a direct comparison with standard errors derived from maximum likelihood estimates used in the reported abundance estimates are challenging. However, the widths of the confidence intervals shrink from 116 in the 3-occasion case, to 56 for the 4-occasion case, to 30 for the 5-occasion case. The symmetry of the distribution of estimates also increases for the greater number of sampling occasions.

## Discussion

Biomass on all 4 grids was relatively low through 1996 (5 years post-fire), and was dominated in the upland habitat (grids 1 and 2) by *Clethrionomys rutilus*, while in the tussock habitat (grids 3 and 4) *Microtus oeconomus* and *Microtus pennsylvanicus* dominated. In 1997, the upland grids saw an influx of *Microtus xanthognathus*. Estimates in this year were hampered by the “near failure” of the depletion criterion (and concomitant large standard error) for *Microtus xanthognathus* abundance estimation on grid 1, leading to the conclusion that this population was nearly infinite, and not being depleted by the 3-occasion removals.

Consistent with the distribution of abundance estimates shown in Figure 4, for 3-occasion sampling events, the potential for large over-estimates of abundance is more extreme (note the long right-tail of the distribution) than for increased number of sampling occasions. Given this behavior of the removal estimator in the 3-occasion application, it is surprising that the observed coefficients of variation were not larger. A clear way to diminish the uncertainty in the abundance estimates

(and consequently in population and community biomass estimates) is to increase the number of sampling occasions.

At the resumption of sampling in 1999, all 4 grids saw the domination of *Microtus xanthognathus* not only in absolute abundance, but also in terms of population biomass. While on the upland grids, *Clethrionomys rutilus* maintained their levels of biomass consistent with the period 1993-1997, the tussock grids saw the complete disappearance of the 2 other species of *Microtus*.

Population biomass of shrews (*Sorex sp.*) and lemmings (*Synaptomys borealis* and *Lemmus trimuncronatus*) were unremarkable, and contributed little to the overall community biomass except in 1997 when lemming biomass on grid 2 rivaled that of *Microtus xanthognathus*.

It appears that the more mesic, tussock habitats are capable of supporting a larger standing crop of *Microtus xanthognathus* than the xeric upland habitat. However these estimates of biomass, in the range of  $5 \text{ kg}\cdot\text{ha}^{-1}$  is roughly comparable with estimates of moose (*Alces alces*) biomass per unit area in the Tanana floodplain (Flora 2002).

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**Table 1.** Average individual mass estimates (g) from specimens weighed during small mammal investigations at Mouse Lake, Kanuti National Wildlife Refuge 1993-2002. Dashes (—) indicate no mass measurements available when associated with individual mass, and indicate either no mass measurements made, or sample size <2 when appearing in the variance column.

Year	Grid	Species group	Individual mass	Variance (individual mass)
1993	1	<i>Clethrionomys rutilus</i>	17.9	6.6
1993	1	<i>Microtus xanthognathus</i>	—	—
1993	1	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	22.4	—
1993	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	22.7	106.8
1993	1	<i>Sorex</i> sp.	3.9	0.3
1993	2	<i>Clethrionomys rutilus</i>	17.9	14.4
1993	2	<i>Microtus xanthognathus</i>	59.6	386.4
1993	2	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	28.5	—
1993	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	26.0	99.6
1993	2	<i>Sorex</i> sp.	3.3	0.2
1993	3	<i>Clethrionomys rutilus</i>	18.4	7.7
1993	3	<i>Microtus xanthognathus</i>	—	—
1993	3	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	23.9	—
1993	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	21.3	69.1
1993	3	<i>Sorex</i> sp.	3.6	0.1
1993	4	<i>Clethrionomys rutilus</i>	17.4	3.8
1993	4	<i>Microtus xanthognathus</i>	—	—
1993	4	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	—	—
1993	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	21.5	35.7
1993	4	<i>Sorex</i> sp.	3.9	0.2
1994	1	<i>Clethrionomys rutilus</i>	19.1	14.7
1994	1	<i>Microtus xanthognathus</i>	—	—
1994	1	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	—	—
1994	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	21.4	18.6
1994	1	<i>Sorex</i> sp.	3.5	0.6
1994	2	<i>Clethrionomys rutilus</i>	17.2	40.2
1994	2	<i>Microtus xanthognathus</i>	—	—
1994	2	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	—	—
1994	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	—	—
1994	2	<i>Sorex</i> sp.	3.5	0.5
1994	3	<i>Clethrionomys rutilus</i>	19.3	4.6
1994	3	<i>Microtus xanthognathus</i>	—	—
1994	3	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	—	—
1994	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	22.8	60.3
1994	3	<i>Sorex</i> sp.	4.5	4.5
1994	4	<i>Clethrionomys rutilus</i>	19.2	6.6
1994	4	<i>Microtus xanthognathus</i>	—	—
1994	4	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	—	—
1994	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	24.0	43.4
1994	4	<i>Sorex</i> sp.	4.0	3.0
1996	1	<i>Clethrionomys rutilus</i>	22.1	17.9
1996	1	<i>Microtus xanthognathus</i>	53.5	54.3
1996	1	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	34.3	300.0
1996	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	24.4	111.3
1996	1	<i>Sorex</i> sp.	4.3	1.4
1996	2	<i>Clethrionomys rutilus</i>	20.7	35.2
1996	2	<i>Microtus xanthognathus</i>	56.6	36.0

Year	Grid	Species group	Individual mass	Variance (individual mass)
1996	2	Synaptomys sp. and Lemmus sp.	25.8	50.4
1996	2	Microtus sp. (excluding M. xanthognathus)	18.9	3.9
1996	2	Sorex sp.	4.4	0.9
1996	3	Clethrionomys rutilus	—	—
1996	3	Microtus xanthognathus	—	—
1996	3	Synaptomys sp. and Lemmus sp.	41.0	146.4
1996	3	Microtus sp. (excluding M. xanthognathus)	22.5	128.1
1996	3	Sorex sp.	5.1	3.2
1996	4	Clethrionomys rutilus	—	—
1996	4	Microtus xanthognathus	—	—
1996	4	Synaptomys sp. and Lemmus sp.	26.9	67.5
1996	4	Microtus sp. (excluding M. xanthognathus)	22.5	60.8
1996	4	Sorex sp.	5.1	4.1
1997	1	Clethrionomys rutilus	20.1	2.7
1997	1	Microtus xanthognathus	60.5	408.0
1997	1	Synaptomys sp. and Lemmus sp.	36.5	279.9
1997	1	Microtus sp. (excluding M. xanthognathus)	30.7	210.3
1997	1	Sorex sp.	5.2	44.4
1997	2	Clethrionomys rutilus	19.6	16.8
1997	2	Microtus xanthognathus	64.5	164.9
1997	2	Synaptomys sp. and Lemmus sp.	27.4	125.7
1997	2	Microtus sp. (excluding M. xanthognathus)	20.5	4.5
1997	2	Sorex sp.	3.6	0.5
1997	3	Clethrionomys rutilus	16.5	0.8
1997	3	Microtus xanthognathus	108.7	—
1997	3	Synaptomys sp. and Lemmus sp.	26.4	95.4
1997	3	Microtus sp. (excluding M. xanthognathus)	20.0	29.4
1997	3	Sorex sp.	3.4	0.2
1997	4	Clethrionomys rutilus	14.4	—
1997	4	Microtus xanthognathus	45.4	211.5
1997	4	Synaptomys sp. and Lemmus sp.	30.9	84.7
1997	4	Microtus sp. (excluding M. xanthognathus)	23.6	563.4
1997	4	Sorex sp.	3.7	0.2
1999	1	Clethrionomys rutilus	17.9	6.0
1999	1	Microtus xanthognathus	59.9	136.2
1999	1	Synaptomys sp. and Lemmus sp.	33.5	189.3
1999	1	Microtus sp. (excluding M. xanthognathus)	—	—
1999	1	Sorex sp.	3.5	0.6
1999	2	Clethrionomys rutilus	20.4	18.2
1999	2	Microtus xanthognathus	52.3	340.1
1999	2	Synaptomys sp. and Lemmus sp.	29.3	81.1
1999	2	Microtus sp. (excluding M. xanthognathus)	—	—
1999	2	Sorex sp.	2.9	0.1
1999	3	Clethrionomys rutilus	20.9	12.3
1999	3	Microtus xanthognathus	48.8	833.8
1999	3	Synaptomys sp. and Lemmus sp.	—	—
1999	3	Microtus sp. (excluding M. xanthognathus)	—	—
1999	3	Sorex sp.	3.6	0.4
1999	4	Clethrionomys rutilus	17.7	3.0
1999	4	Microtus xanthognathus	53.1	108.7
1999	4	Synaptomys sp. and Lemmus sp.	23.9	10.2
1999	4	Microtus sp. (excluding M. xanthognathus)	—	—

Year	Grid	Species group	Individual mass	Variance (individual mass)
1999	4	Sorex sp.	3.2	0.2
2000	1	Clethrionomys rutilus	20.0	1.4
2000	1	Microtus xanthognathus	61.6	210.6
2000	1	Synaptomys sp. and Lemmus sp.	36.3	28.5
2000	1	Microtus sp. (excluding M. xanthognathus)	16.0	—
2000	1	Sorex sp.	4.0	1.4
2000	2	Clethrionomys rutilus	20.5	0.5
2000	2	Microtus xanthognathus	56.5	612.5
2000	2	Synaptomys sp. and Lemmus sp.	27.4	138.7
2000	2	Microtus sp. (excluding M. xanthognathus)	19.3	—
2000	2	Sorex sp.	3.4	0.2
2000	3	Clethrionomys rutilus	20.0	23.2
2000	3	Microtus xanthognathus	49.1	298.8
2000	3	Synaptomys sp. and Lemmus sp.	—	—
2000	3	Microtus sp. (excluding M. xanthognathus)	25.2	—
2000	3	Sorex sp.	3.4	0.1
2000	4	Clethrionomys rutilus	19.7	11.6
2000	4	Microtus xanthognathus	53.8	416.4
2000	4	Synaptomys sp. and Lemmus sp.	28.1	125.4
2000	4	Microtus sp. (excluding M. xanthognathus)	21.6	—
2000	4	Sorex sp.	3.7	0.8
2001	1	Clethrionomys rutilus	19.9	2.9
2001	1	Microtus xanthognathus	57.1	291.8
2001	1	Synaptomys sp. and Lemmus sp.	29.1	3.0
2001	1	Microtus sp. (excluding M. xanthognathus)	—	—
2001	1	Sorex sp.	3.5	0.2
2001	2	Clethrionomys rutilus	19.3	2.7
2001	2	Microtus xanthognathus	59.6	404.5
2001	2	Synaptomys sp. and Lemmus sp.	23.4	85.8
2001	2	Microtus sp. (excluding M. xanthognathus)	—	—
2001	2	Sorex sp.	3.3	0.1
2001	3	Clethrionomys rutilus	17.4	2.9
2001	3	Microtus xanthognathus	43.7	289.8
2001	3	Synaptomys sp. and Lemmus sp.	—	—
2001	3	Microtus sp. (excluding M. xanthognathus)	—	—
2001	3	Sorex sp.	3.6	0.2
2001	4	Clethrionomys rutilus	18.1	4.8
2001	4	Microtus xanthognathus	50.2	207.4
2001	4	Synaptomys sp. and Lemmus sp.	22.9	1.5
2001	4	Microtus sp. (excluding M. xanthognathus)	—	—
2001	4	Sorex sp.	3.9	1.0
2002	1	Clethrionomys rutilus	24.1	33.3
2002	1	Microtus xanthognathus	64.3	405.4
2002	1	Synaptomys sp. and Lemmus sp.	36.9	29.8
2002	1	Microtus sp. (excluding M. xanthognathus)	—	—
2002	1	Sorex sp.	3.9	1.1
2002	2	Clethrionomys rutilus	20.0	10.5
2002	2	Microtus xanthognathus	64.3	116.5
2002	2	Synaptomys sp. and Lemmus sp.	33.6	165.8
2002	2	Microtus sp. (excluding M. xanthognathus)	—	—
2002	2	Sorex sp.	3.3	0.5
2002	3	Clethrionomys rutilus	20.2	7.1

Year	Grid	Species group	Individual mass	Variance (individual mass)
2002	3	<i>Microtus xanthognathus</i>	60.4	222.0
2002	3	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	—	—
2002	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	—	—
2002	3	<i>Sorex</i> sp.	3.4	—
2002	4	<i>Clethrionomys rutilus</i>	18.9	0.7
2002	4	<i>Microtus xanthognathus</i>	58.7	90.5
2002	4	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	19.5	18.7
2002	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	—	—
2002	4	<i>Sorex</i> sp.	2.9	—

Table 2. Abundance estimates by year, grid, and species group during small mammal investigations at Mouse Lake, Kanuti National Wildlife Refuge 1993-2002. Dashes (—) indicate precision of the estimate was not possible because abundance was calculated on the basis of minimum number of animals known to be alive. This resulted when either a) ≤10 individuals were captured, or b) when the depletion criterion (White et al. 1982:108) was not satisfied.

Year	Grid	Species group	Estimated abundance	SE(Estimated abundance)
1993	1	<i>Clethrionomys rutilus</i>	27.29	16.5
1993	1	<i>Microtus xanthognathus</i>	0	—
1993	1	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	1	—
1993	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	12.17	2.74
1993	1	<i>Sorex</i> sp.	14	0.463
1993	2	<i>Clethrionomys rutilus</i>	95.12	141
1993	2	<i>Microtus xanthognathus</i>	3	—
1993	2	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	1	—
1993	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	14	—
1993	2	<i>Sorex</i> sp.	12.17	2.74
1993	3	<i>Clethrionomys rutilus</i>	15	—
1993	3	<i>Microtus xanthognathus</i>	0	—
1993	3	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	1	—
1993	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	66.99	22.9
1993	3	<i>Sorex</i> sp.	8	—
1993	4	<i>Clethrionomys rutilus</i>	21.21	6.15
1993	4	<i>Microtus xanthognathus</i>	0	—
1993	4	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	0	—
1993	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	153.17	28.6
1993	4	<i>Sorex</i> sp.	17.61	4.29
1994	1	<i>Clethrionomys rutilus</i>	8	—
1994	1	<i>Microtus xanthognathus</i>	0	—
1994	1	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	0	—
1994	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	6	—
1994	1	<i>Sorex</i> sp.	11.75	3.79
1994	2	<i>Clethrionomys rutilus</i>	29.36	11
1994	2	<i>Microtus xanthognathus</i>	0	—
1994	2	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	0	—
1994	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	1	—
1994	2	<i>Sorex</i> sp.	9	—
1994	3	<i>Clethrionomys rutilus</i>	6	—
1994	3	<i>Microtus xanthognathus</i>	0	—
1994	3	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	0	—
1994	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	10.03	2.74
1994	3	<i>Sorex</i> sp.	2	—
1994	4	<i>Clethrionomys rutilus</i>	3	—
1994	4	<i>Microtus xanthognathus</i>	0	—
1994	4	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	0	—
1994	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	6	0.142
1994	4	<i>Sorex</i> sp.	3	—
1996	1	<i>Clethrionomys rutilus</i>	23.11	2.1
1996	1	<i>Microtus xanthognathus</i>	9	—
1996	1	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	23.51	9.62
1996	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	17	—
1996	1	<i>Sorex</i> sp.	21	—

Year	Grid	Species group	Estimated abundance	SE(Estimated abundance)
1996	2	Clethrionomys rutilus	13	0.875
1996	2	Microtus xanthognathus	16	10.5
1996	2	Synaptomys sp. and Lemmus sp.	6	—
1996	2	Microtus sp. (excluding M. xanthognathus)	5	—
1996	2	Sorex sp.	25.73	11.2
1996	3	Clethrionomys rutilus	0	—
1996	3	Microtus xanthognathus	0	—
1996	3	Synaptomys sp. and Lemmus sp.	6	—
1996	3	Microtus sp. (excluding M. xanthognathus)	73.91	17.9
1996	3	Sorex sp.	11	—
1996	4	Clethrionomys rutilus	0	—
1996	4	Microtus xanthognathus	0	—
1996	4	Synaptomys sp. and Lemmus sp.	5	—
1996	4	Microtus sp. (excluding M. xanthognathus)	178.33	40.4
1996	4	Sorex sp.	35.21	12.2
1997	1	Clethrionomys rutilus	9	—
1997	1	Microtus xanthognathus	291	284
1997	1	Synaptomys sp. and Lemmus sp.	21	—
1997	1	Microtus sp. (excluding M. xanthognathus)	12	—
1997	1	Sorex sp.	44	—
1997	2	Clethrionomys rutilus	12.18	1.31
1997	2	Microtus xanthognathus	72	25.8
1997	2	Synaptomys sp. and Lemmus sp.	139.33	178
1997	2	Microtus sp. (excluding M. xanthognathus)	13	—
1997	2	Sorex sp.	51.55	10.4
1997	3	Clethrionomys rutilus	3	—
1997	3	Microtus xanthognathus	1	—
1997	3	Synaptomys sp. and Lemmus sp.	33.92	14.1
1997	3	Microtus sp. (excluding M. xanthognathus)	49.59	2.81
1997	3	Sorex sp.	42.16	32.3
1997	4	Clethrionomys rutilus	1	—
1997	4	Microtus xanthognathus	22	2.6
1997	4	Synaptomys sp. and Lemmus sp.	16.5	2.83
1997	4	Microtus sp. (excluding M. xanthognathus)	106.5	15.1
1997	4	Sorex sp.	15	—
1999	1	Clethrionomys rutilus	19.7	4.15
1999	1	Microtus xanthognathus	38	—
1999	1	Synaptomys sp. and Lemmus sp.	3	—
1999	1	Microtus sp. (excluding M. xanthognathus)	0	—
1999	1	Sorex sp.	31	—
1999	2	Clethrionomys rutilus	13	—
1999	2	Microtus xanthognathus	49	40.4
1999	2	Synaptomys sp. and Lemmus sp.	3	—
1999	2	Microtus sp. (excluding M. xanthognathus)	0	—
1999	2	Sorex sp.	29	—
1999	3	Clethrionomys rutilus	6	—
1999	3	Microtus xanthognathus	38	5
1999	3	Synaptomys sp. and Lemmus sp.	0	—
1999	3	Microtus sp. (excluding M. xanthognathus)	0	—
1999	3	Sorex sp.	22	—
1999	4	Clethrionomys rutilus	5	—
1999	4	Microtus xanthognathus	35	3
1999	4	Synaptomys sp. and Lemmus sp.	4	—

Year	Grid	Species group	Estimated abundance	SE(Estimated abundance)
1999	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
1999	4	<i>Sorex</i> sp.	63.32	80.3
2000	1	<i>Clethrionomys rutilus</i>	12	—
2000	1	<i>Microtus xanthognathus</i>	77	—
2000	1	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	5	—
2000	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2000	1	<i>Sorex</i> sp.	18	—
2000	2	<i>Clethrionomys rutilus</i>	4	—
2000	2	<i>Microtus xanthognathus</i>	57	17.7
2000	2	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	8	—
2000	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	1	—
2000	2	<i>Sorex</i> sp.	15	—
2000	3	<i>Clethrionomys rutilus</i>	3	—
2000	3	<i>Microtus xanthognathus</i>	133	74.2
2000	3	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	0	—
2000	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	1	—
2000	3	<i>Sorex</i> sp.	9	—
2000	4	<i>Clethrionomys rutilus</i>	9	—
2000	4	<i>Microtus xanthognathus</i>	136	115.1
2000	4	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	5	—
2000	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	1	—
2000	4	<i>Sorex</i> sp.	13	—
2001	1	<i>Clethrionomys rutilus</i>	6	—
2001	1	<i>Microtus xanthognathus</i>	70	8
2001	1	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	4	—
2001	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2001	1	<i>Sorex</i> sp.	30.7	7.98
2001	2	<i>Clethrionomys rutilus</i>	9	—
2001	2	<i>Microtus xanthognathus</i>	59	21
2001	2	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	11	0.788
2001	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2001	2	<i>Sorex</i> sp.	35.64	19.1
2001	3	<i>Clethrionomys rutilus</i>	5	—
2001	3	<i>Microtus xanthognathus</i>	58	8
2001	3	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	0	—
2001	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2001	3	<i>Sorex</i> sp.	19	—
2001	4	<i>Clethrionomys rutilus</i>	4	—
2001	4	<i>Microtus xanthognathus</i>	97	33.5
2001	4	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	3	—
2001	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2001	4	<i>Sorex</i> sp.	45.66	50.4
2002	1	<i>Clethrionomys rutilus</i>	21.54	2.61
2002	1	<i>Microtus xanthognathus</i>	75.66	6.81
2002	1	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	7	—
2002	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2002	1	<i>Sorex</i> sp.	6	—
2002	2	<i>Clethrionomys rutilus</i>	27.68	4.59
2002	2	<i>Microtus xanthognathus</i>	82.88	9.31
2002	2	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	4	—
2002	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2002	2	<i>Sorex</i> sp.	8	—
2002	3	<i>Clethrionomys rutilus</i>	24.53	20

Year	Grid	Species group	Estimated abundance	SE(Estimated abundance)
2002	3	<i>Microtus xanthognathus</i>	139.89	21.4
2002	3	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	0	—
2002	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2002	3	<i>Sorex</i> sp.	5	—
2002	4	<i>Clethrionomys rutilus</i>	10	—
2002	4	<i>Microtus xanthognathus</i>	180.03	14.4
2002	4	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	5	—
2002	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2002	4	<i>Sorex</i> sp.	2	—

Table 3. Estimated biomass (g) by year, grid, and species group during small mammal investigations at Mouse Lake, Kanuti National Wildlife Refuge 1993-2002. Dashes (—) indicate precision of the estimate was incalculable because precision was not estimated for either average individual mass or abundance on the plot.

Year	Grid	Species group	Estimated biomass	SE(biomass)
1993	1	<i>Clethrionomys rutilus</i>	487	303
1993	1	<i>Microtus xanthognathus</i>	0	—
1993	1	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	22	—
1993	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	277	140
1993	1	<i>Sorex</i> sp.	55	8
1993	2	<i>Clethrionomys rutilus</i>	1699	2544
1993	2	<i>Microtus xanthognathus</i>	179	—
1993	2	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	29	—
1993	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	363	—
1993	2	<i>Sorex</i> sp.	40	10
1993	3	<i>Clethrionomys rutilus</i>	276	—
1993	3	<i>Microtus xanthognathus</i>	0	—
1993	3	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	24	—
1993	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	1428	740
1993	3	<i>Sorex</i> sp.	29	—
1993	4	<i>Clethrionomys rutilus</i>	369	115
1993	4	<i>Microtus xanthognathus</i>	0	—
1993	4	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	0	—
1993	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	3286	1101
1993	4	<i>Sorex</i> sp.	69	19
1994	1	<i>Clethrionomys rutilus</i>	153	—
1994	1	<i>Microtus xanthognathus</i>	0	—
1994	1	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	0	—
1994	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	128	—
1994	1	<i>Sorex</i> sp.	41	16
1994	2	<i>Clethrionomys rutilus</i>	505	265
1994	2	<i>Microtus xanthognathus</i>	0	—
1994	2	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	0	—
1994	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
1994	2	<i>Sorex</i> sp.	31	—
1994	3	<i>Clethrionomys rutilus</i>	116	—
1994	3	<i>Microtus xanthognathus</i>	0	—
1994	3	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	0	—
1994	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	228	100
1994	3	<i>Sorex</i> sp.	9	—
1994	4	<i>Clethrionomys rutilus</i>	58	—
1994	4	<i>Microtus xanthognathus</i>	0	—
1994	4	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	0	—
1994	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	144	40
1994	4	<i>Sorex</i> sp.	12	—
1996	1	<i>Clethrionomys rutilus</i>	510	108
1996	1	<i>Microtus xanthognathus</i>	482	—
1996	1	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	807	524
1996	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	414	—
1996	1	<i>Sorex</i> sp.	90	—
1996	2	<i>Clethrionomys rutilus</i>	269	79
1996	2	<i>Microtus xanthognathus</i>	905	602
1996	2	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	155	—

Year	Grid	Species group	Estimated biomass	SE(biomass)
1996	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	95	—
1996	2	<i>Sorex</i> sp.	113	55
1996	3	<i>Clethrionomys rutilus</i>	0	—
1996	3	<i>Microtus xanthognathus</i>	0	—
1996	3	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	246	—
1996	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	1665	929
1996	3	<i>Sorex</i> sp.	57	—
1996	4	<i>Clethrionomys rutilus</i>	0	—
1996	4	<i>Microtus xanthognathus</i>	0	—
1996	4	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	135	—
1996	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	4011	1661
1996	4	<i>Sorex</i> sp.	179	95
1997	1	<i>Clethrionomys rutilus</i>	181	—
1997	1	<i>Microtus xanthognathus</i>	17607	18161
1997	1	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	766	—
1997	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	368	—
1997	1	<i>Sorex</i> sp.	227	—
1997	2	<i>Clethrionomys rutilus</i>	239	56
1997	2	<i>Microtus xanthognathus</i>	4641	1903
1997	2	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	3819	5123
1997	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	266	—
1997	2	<i>Sorex</i> sp.	184	52
1997	3	<i>Clethrionomys rutilus</i>	49	—
1997	3	<i>Microtus xanthognathus</i>	109	—
1997	3	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	896	498
1997	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	993	275
1997	3	<i>Sorex</i> sp.	144	111
1997	4	<i>Clethrionomys rutilus</i>	14	—
1997	4	<i>Microtus xanthognathus</i>	1000	341
1997	4	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	510	175
1997	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	2509	2553
1997	4	<i>Sorex</i> sp.	55	—
1999	1	<i>Clethrionomys rutilus</i>	352	88
1999	1	<i>Microtus xanthognathus</i>	2276	—
1999	1	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	101	—
1999	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
1999	1	<i>Sorex</i> sp.	108	—
1999	2	<i>Clethrionomys rutilus</i>	266	—
1999	2	<i>Microtus xanthognathus</i>	2565	2300
1999	2	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	88	—
1999	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
1999	2	<i>Sorex</i> sp.	84	—
1999	3	<i>Clethrionomys rutilus</i>	126	—
1999	3	<i>Microtus xanthognathus</i>	1856	1124
1999	3	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	0	—
1999	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
1999	3	<i>Sorex</i> sp.	79	—
1999	4	<i>Clethrionomys rutilus</i>	89	—
1999	4	<i>Microtus xanthognathus</i>	1858	398
1999	4	<i>Synaptomys</i> sp. and <i>Lemmus</i> sp.	96	—
1999	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
1999	4	<i>Sorex</i> sp.	202	258
2000	1	<i>Clethrionomys rutilus</i>	240	—

Year	Grid	Species group	Estimated biomass	SE(biomass)
2000	1	<i>Microtus</i> xanthognathus	4744	—
2000	1	Synaptomys sp. and <i>Lemmus</i> sp.	182	—
2000	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2000	1	<i>Sorex</i> sp.	73	—
2000	2	<i>Clethrionomys rutilus</i>	82	—
2000	2	<i>Microtus</i> xanthognathus	3221	1729
2000	2	Synaptomys sp. and <i>Lemmus</i> sp.	219	—
2000	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	19	—
2000	2	<i>Sorex</i> sp.	51	—
2000	3	<i>Clethrionomys rutilus</i>	60	—
2000	3	<i>Microtus</i> xanthognathus	6526	4306
2000	3	Synaptomys sp. and <i>Lemmus</i> sp.	0	—
2000	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	25	—
2000	3	<i>Sorex</i> sp.	31	—
2000	4	<i>Clethrionomys rutilus</i>	177	—
2000	4	<i>Microtus</i> xanthognathus	7313	6783
2000	4	Synaptomys sp. and <i>Lemmus</i> sp.	141	—
2000	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	22	—
2000	4	<i>Sorex</i> sp.	48	—
2001	1	<i>Clethrionomys rutilus</i>	119	—
2001	1	<i>Microtus</i> xanthognathus	3994	1280
2001	1	Synaptomys sp. and <i>Lemmus</i> sp.	117	—
2001	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2001	1	<i>Sorex</i> sp.	106	31
2001	2	<i>Clethrionomys rutilus</i>	174	—
2001	2	<i>Microtus</i> xanthognathus	3513	1724
2001	2	Synaptomys sp. and <i>Lemmus</i> sp.	258	104
2001	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2001	2	<i>Sorex</i> sp.	118	65
2001	3	<i>Clethrionomys rutilus</i>	87	—
2001	3	<i>Microtus</i> xanthognathus	2534	1047
2001	3	Synaptomys sp. and <i>Lemmus</i> sp.	0	—
2001	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2001	3	<i>Sorex</i> sp.	68	—
2001	4	<i>Clethrionomys rutilus</i>	72	—
2001	4	<i>Microtus</i> xanthognathus	4865	2185
2001	4	Synaptomys sp. and <i>Lemmus</i> sp.	69	—
2001	4	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2001	4	<i>Sorex</i> sp.	179	203
2002	1	<i>Clethrionomys rutilus</i>	519	139
2002	1	<i>Microtus</i> xanthognathus	4869	1585
2002	1	Synaptomys sp. and <i>Lemmus</i> sp.	259	—
2002	1	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2002	1	<i>Sorex</i> sp.	23	—
2002	2	<i>Clethrionomys rutilus</i>	555	128
2002	2	<i>Microtus</i> xanthognathus	5326	1076
2002	2	Synaptomys sp. and <i>Lemmus</i> sp.	135	—
2002	2	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—
2002	2	<i>Sorex</i> sp.	27	—
2002	3	<i>Clethrionomys rutilus</i>	496	410
2002	3	<i>Microtus</i> xanthognathus	8455	2453
2002	3	Synaptomys sp. and <i>Lemmus</i> sp.	0	—
2002	3	<i>Microtus</i> sp. (excluding <i>M. xanthognathus</i> )	0	—

Year	Grid	Species group	Estimated biomass	SE(biomass)
2002	3	Sorex sp.	17	—
2002	4	Clethrionomys rutilus	189	—
2002	4	Microtus xanthognathus	10564	1910
2002	4	Synaptomys sp. and Lemmus sp.	97	—
2002	4	Microtus sp. (excluding M. xanthognathus)	0	—
2002	4	Sorex sp.	6	—

Table 4. Aggregated biomass estimates from Table 3 for standing crop (g) of small mammal biomass during small mammal investigations at Mouse Lake, Kanuti National Wildlife Refuge 1993-2002.

Year	Grid	Estimated community biomass	SE(Estimated community biomass)
1993	1	841	334
1993	2	2310	2544
1993	3	1757	740
1993	4	3724	1108
1994	1	322	16
1994	2	536	265
1994	3	353	100
1994	4	213	40
1996	1	2304	535
1996	2	1536	610
1996	3	1967	929
1996	4	4325	1664
1997	1	19149	18161
1997	2	9149	5465
1997	3	2190	580
1997	4	4088	2581
1999	1	2836	88
1999	2	3003	2300
1999	3	2061	1124
1999	4	2244	475
2000	1	5239	—
2000	2	3593	1729
2000	3	6642	4306
2000	4	7700	6783
2001	1	4336	1280
2001	2	4063	1728
2001	3	2688	1047
2001	4	5185	2194
2002	1	5670	1591
2002	2	6042	1084
2002	3	8968	2487
2002	4	10856	1910

Figure 1. Location of trapping grids during small mammal investigations at Mouse Lake, Kanuti National Wildlife Refuge 1993-2002 (Saperstein 2002). Habitat descriptions of the grids can be found in Saperstein (2002).

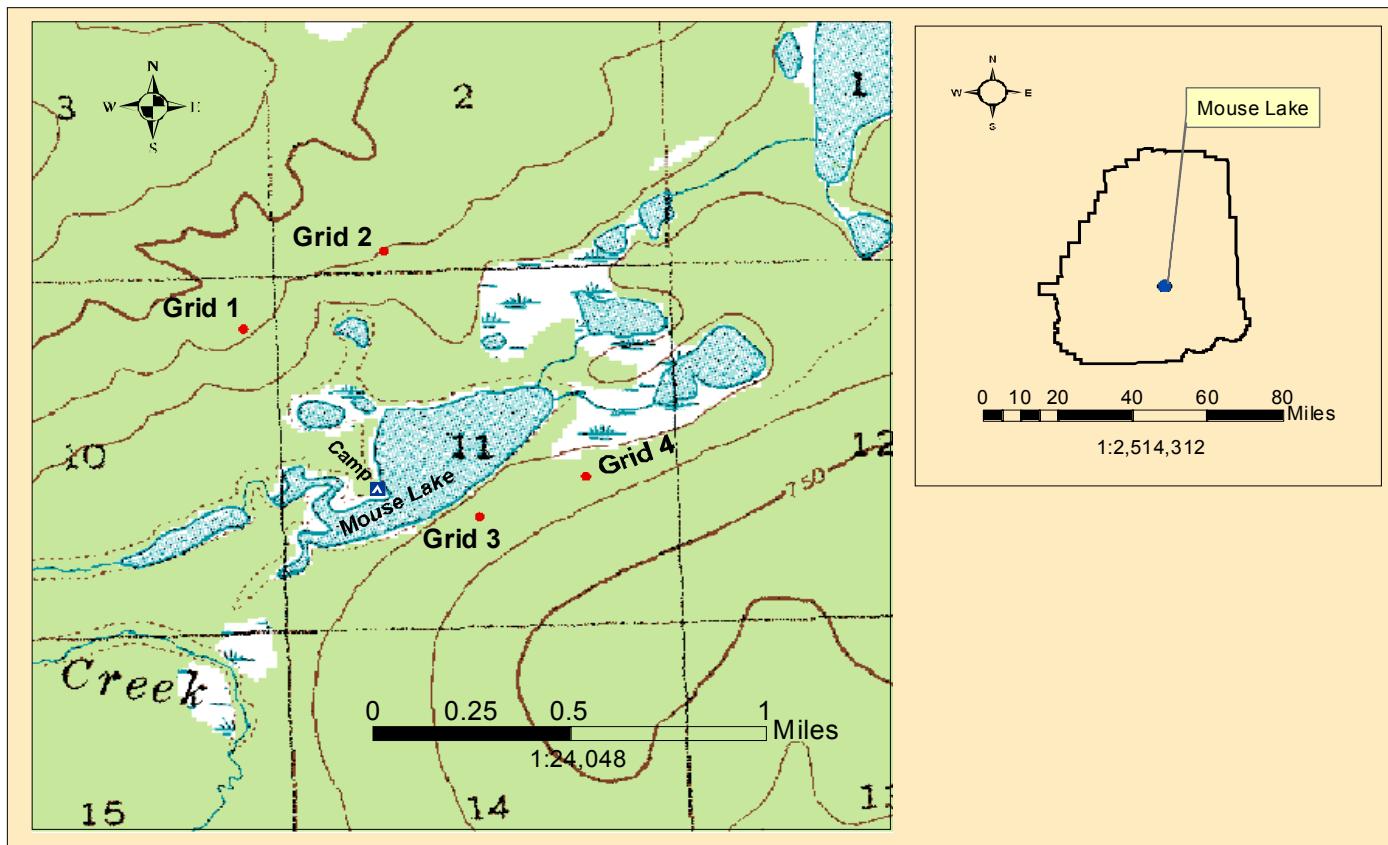
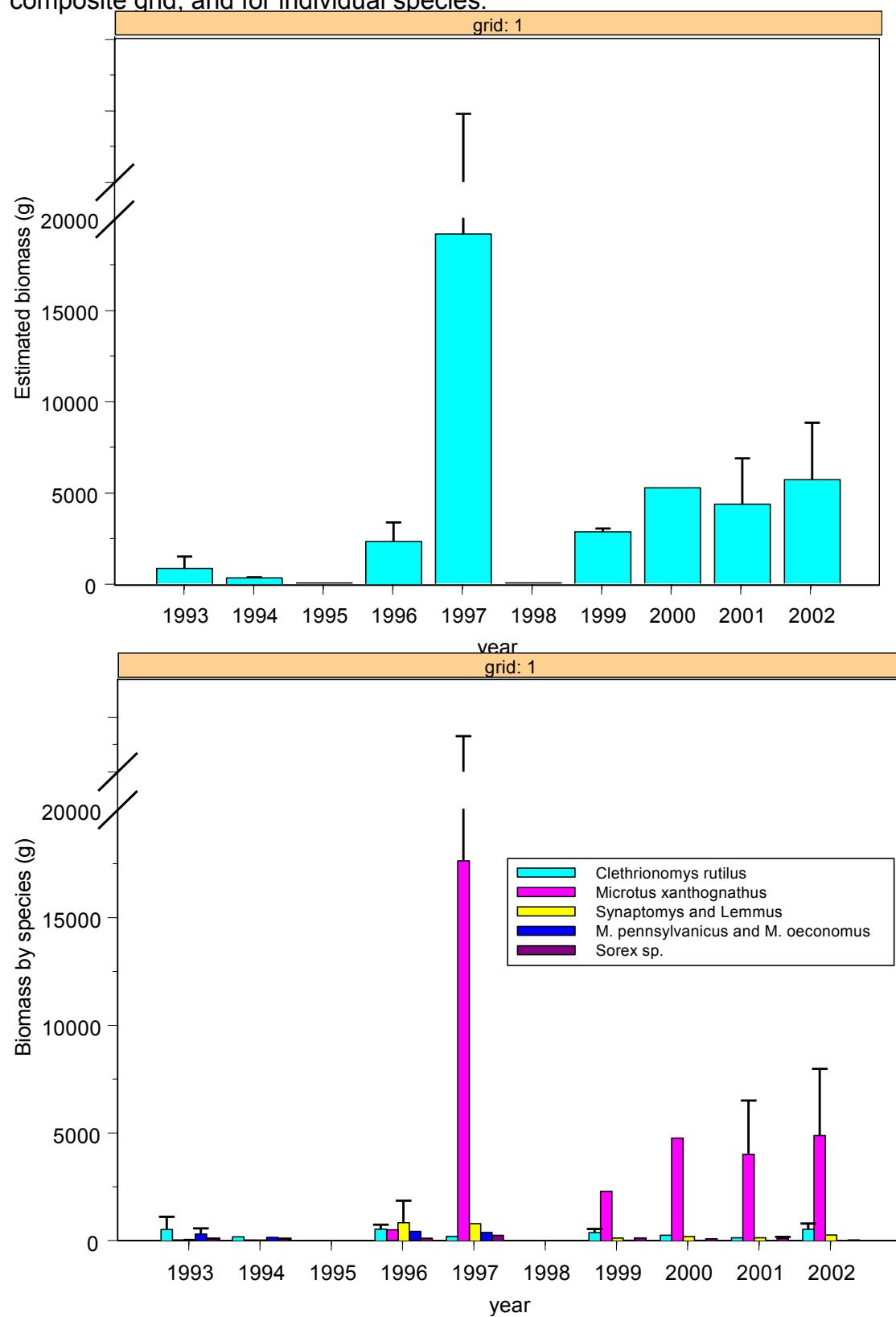


Figure 2. Estimated small mammal biomass on 4 sampling grids during small mammal investigations at Mouse Lake, Kanuti National Wildlife Refuge 1993-2002. Error bars, when precision could be estimated, represent 95% confidence bounds both for the composite grid, and for individual species.



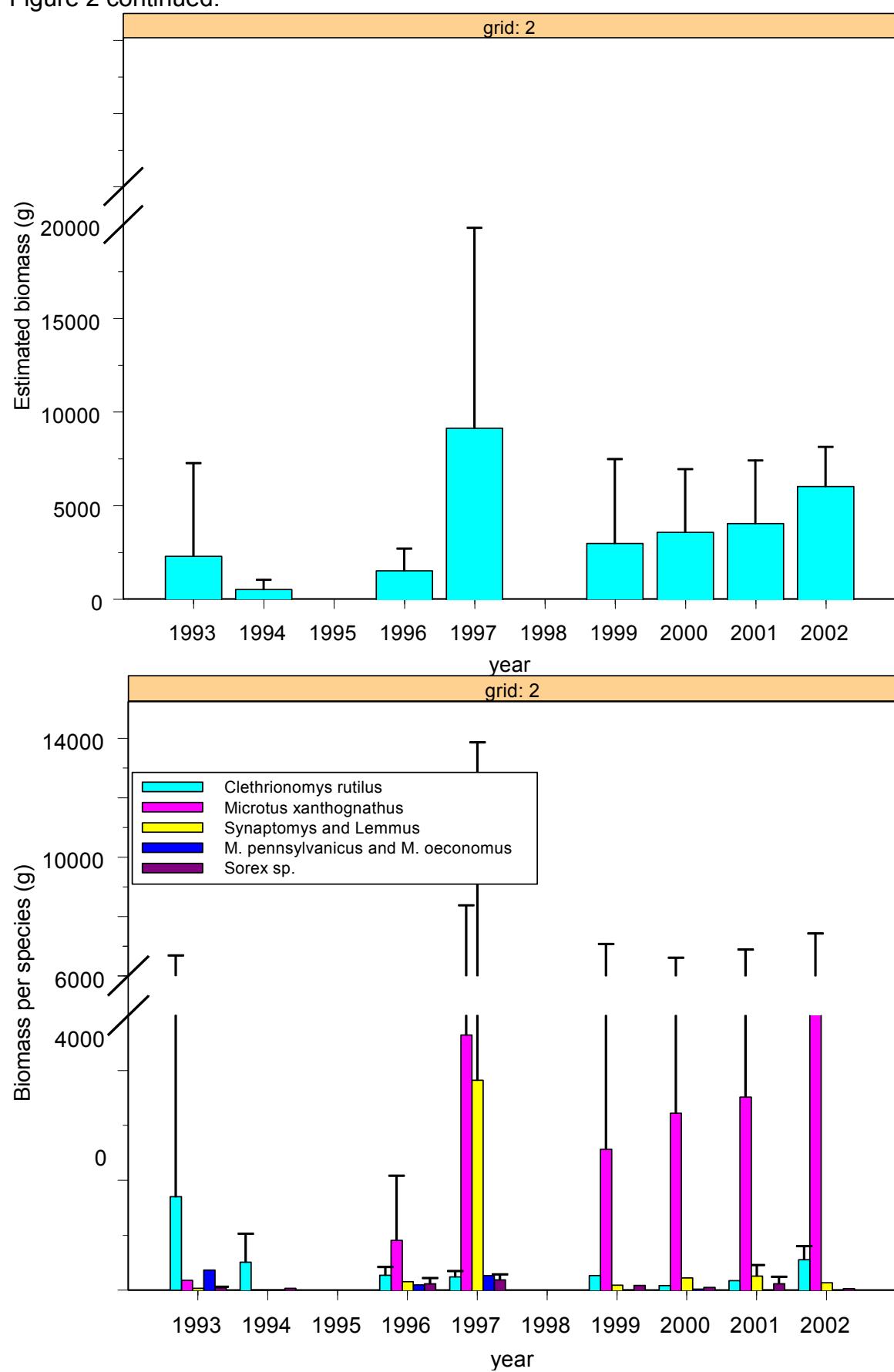


Figure 2  
continued.

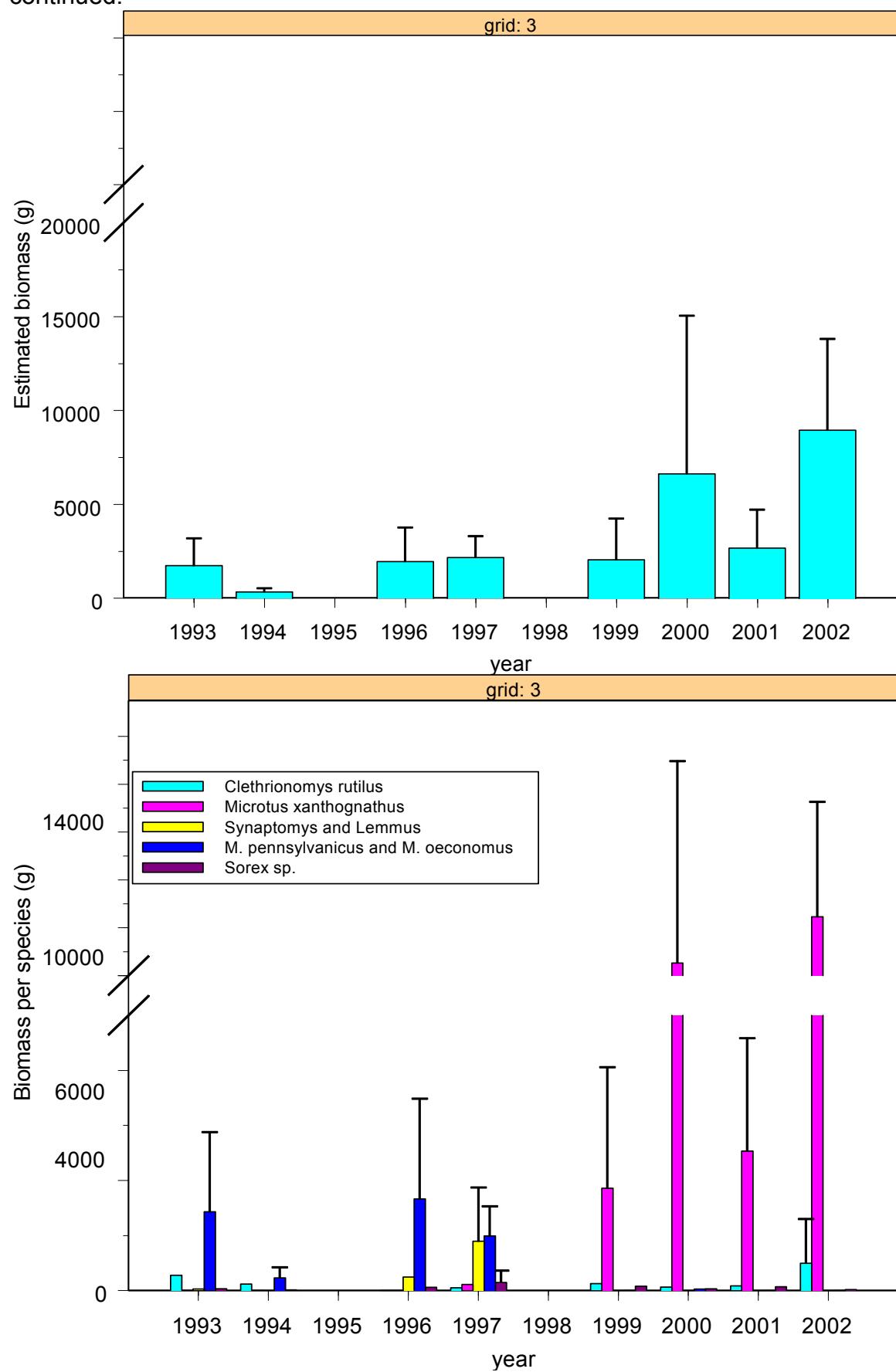


Figure 2  
continued.

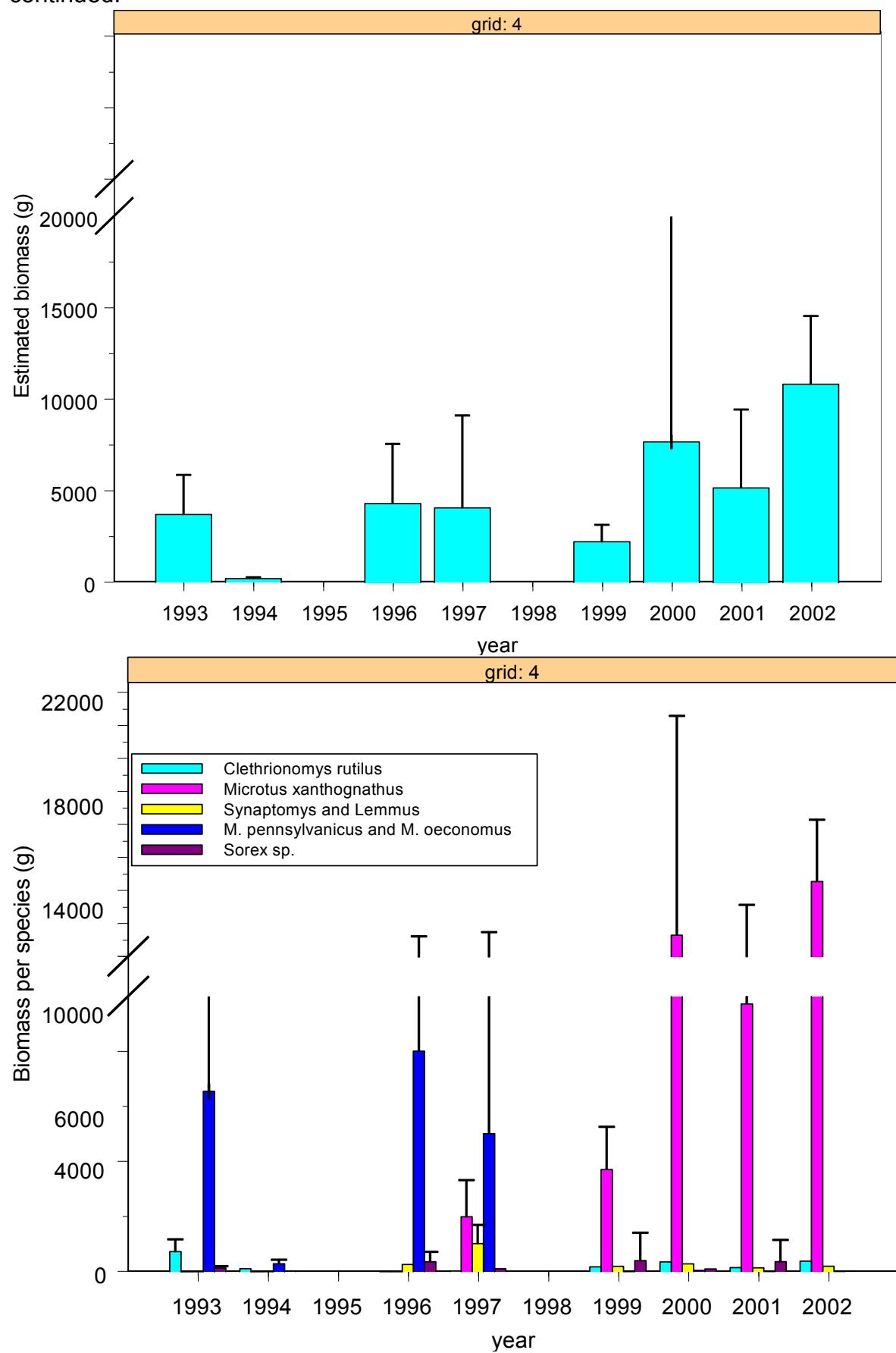


Figure 3, Size distribution histograms for individual weights of a) *Clethrionomys rutilus*, b) *Synaptomys borealis* and *Lemmus trimuncronatus*, and c) *Microtus xanthognathus*. Distributions are not subdivided by grid because sample sizes would be too diminished.

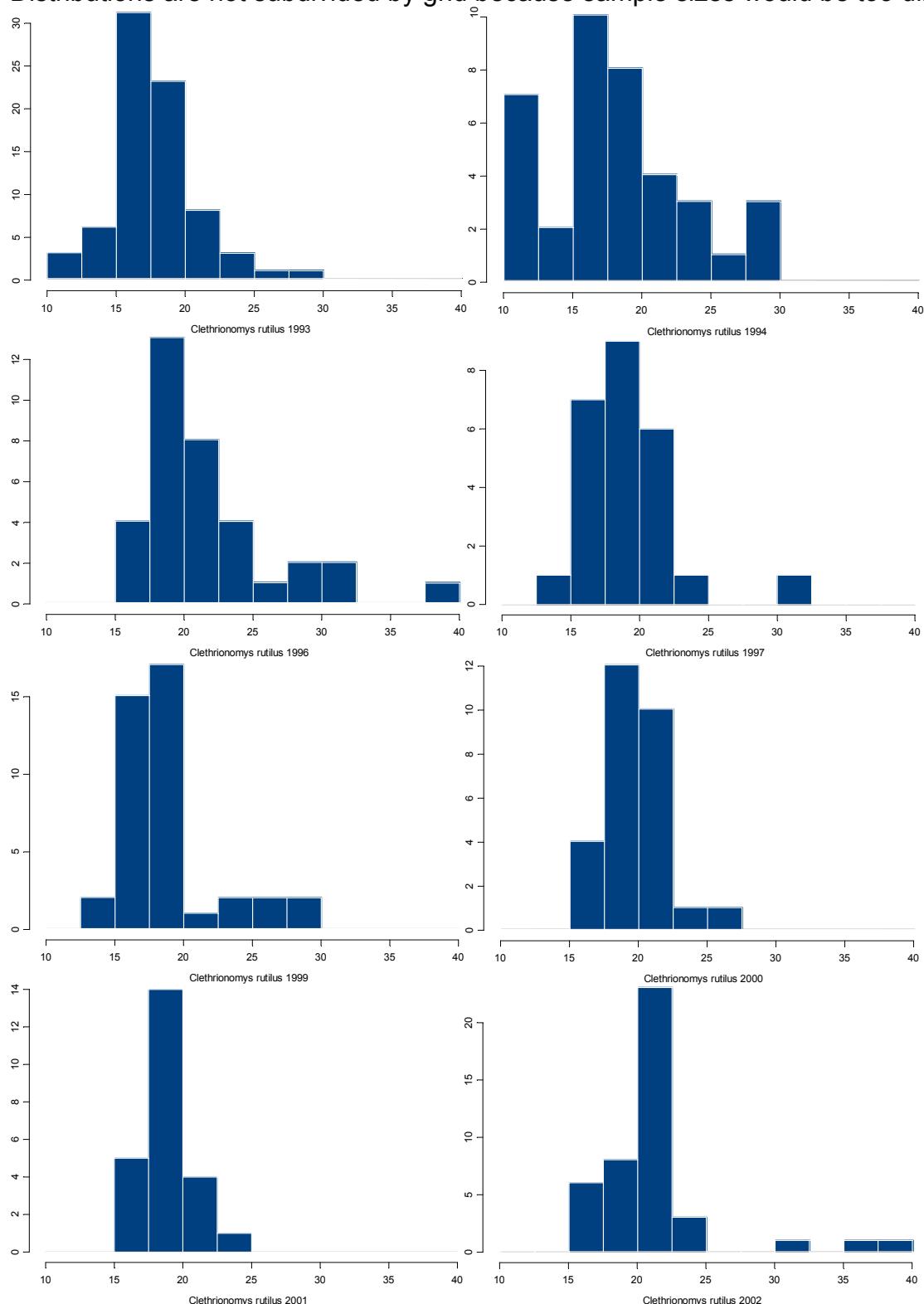
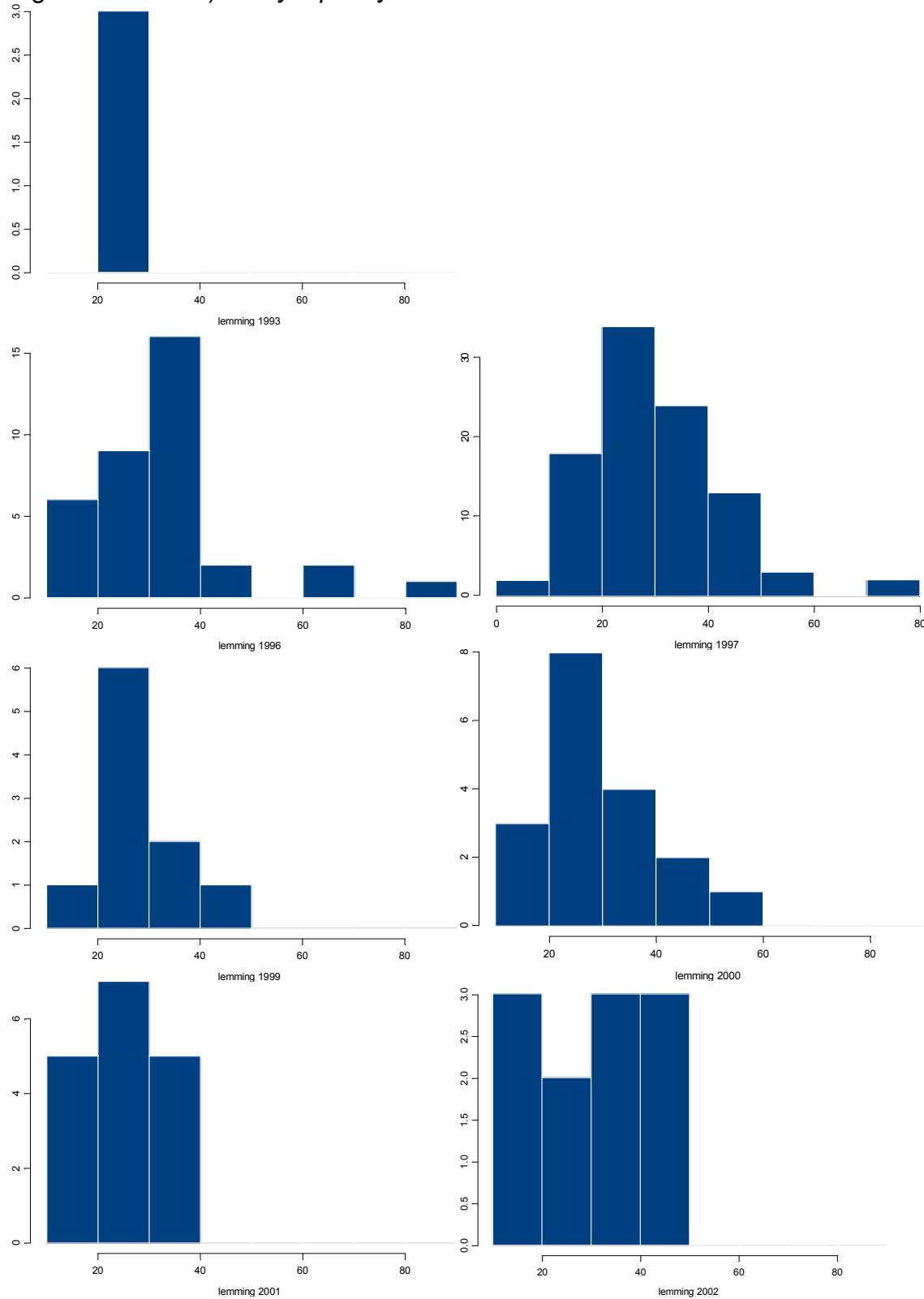


Figure 3. Panel b) for *Synaptomys borealis* and *Lemmus trimuncronatus*

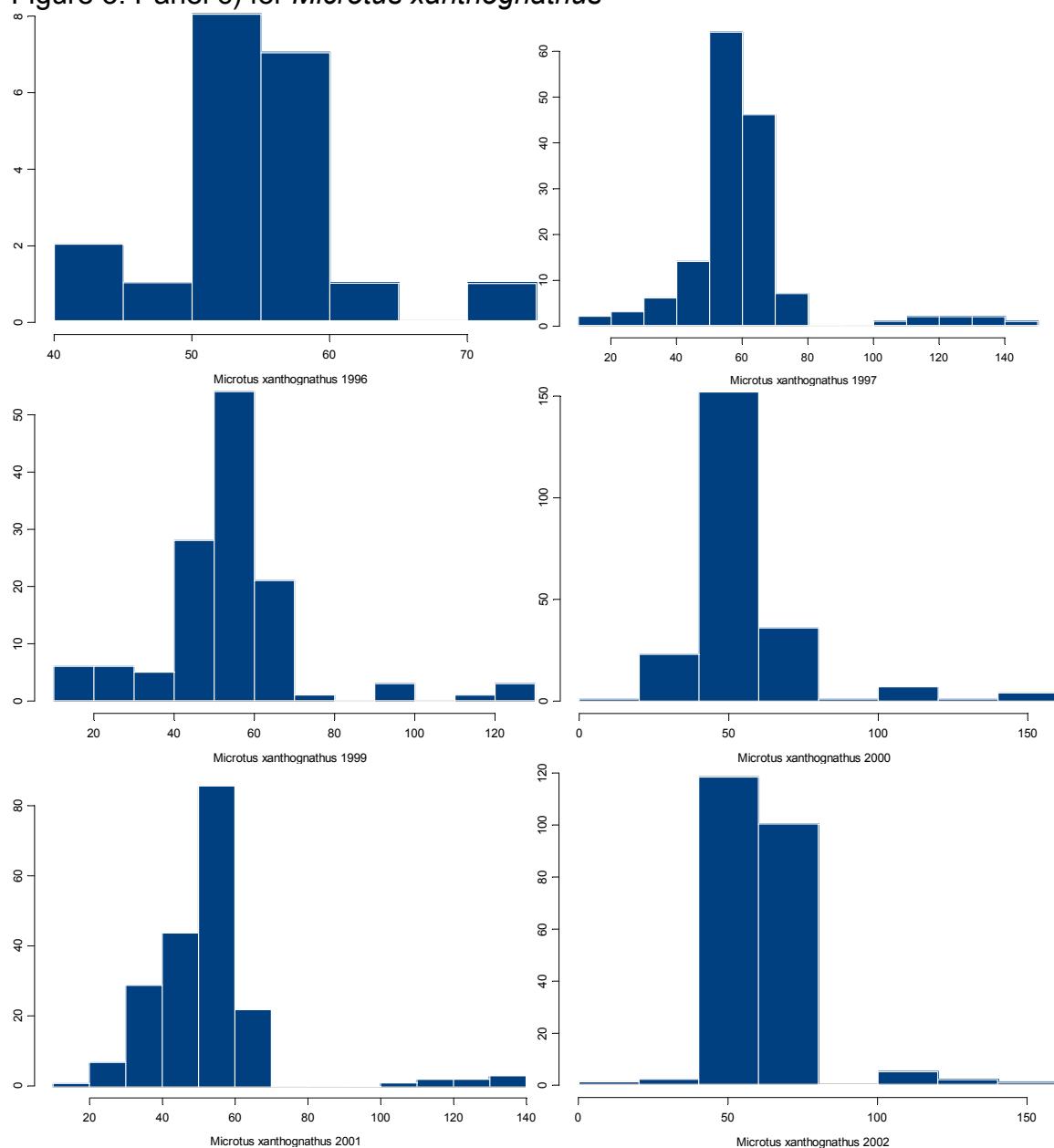
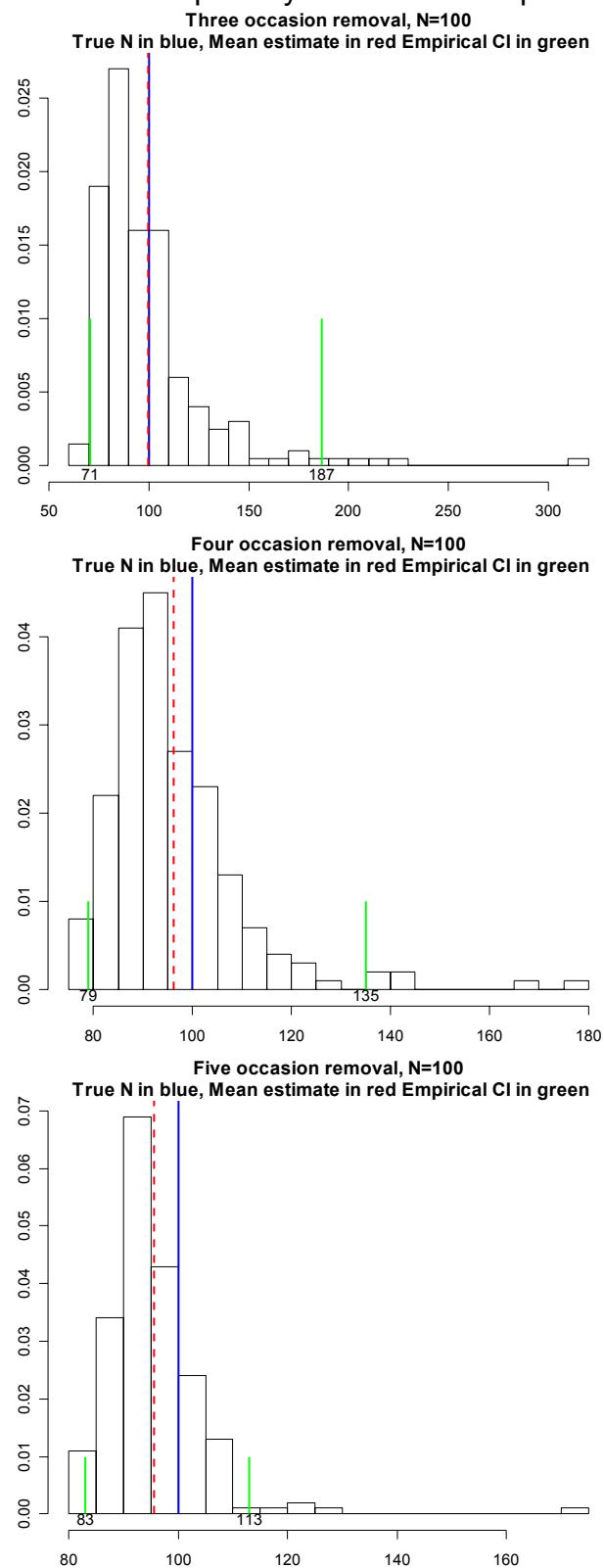


Figure 4. Simulation example (200 replicates each) showing the bias (difference between average estimate and true abundance  $N=100$  in all cases), and precision calculated empirically from the 200 replicates)



## Appendix A. Routine for calculating empirical confidence intervals for k-occasion removal estimator, using WisP library of Borchers et al. (2002) in the R-language.

```

# Simulation of Mouse Lake Kanuti sampling
mouse.lake <- generate.region(x.length=100, y.width=100)

# Uniform density across the grid

clru.density <- generate.density()
#plot(clru.density, mouse.lake, eye.horiz=330, eye.vert=35)

# Define the CLRU population

clru.pars <- setpars.population(mouse.lake, clru.density, number.groups=100,
                                 exposure.method="beta", exposure.min=0, exposure.max=1,
                                 exposure.mean=.5, exposure.shape=.3)
clru.pop <- generate.population(clru.pars)

# Establish removal sampling design

clru.design <- generate.design.rm(mouse.lake, n.occ=3)

# Establish removal survey

clru.survey <- setpars.survey.rm(clru.pop, clru.design, pmin=0.1, pmax=0.5, improvement=0)
clru.sample <- generate.sample.rm(clru.survey)

# See what we caught

summary(clru.sample)
plot.sample.rm(clru.sample, whole.population=T)

# Produce estimates

point.est.rm(clru.sample, numerical=T, plot=T)

# Produce confidence bounds can't be accomplished for n.occ > 2

# int.est.rm(clru.sample)

# So, create empirical distribution and confidence bounds via simulation
# Create container (est) to hold replicate estimates

i <- 0
est <- rep(0,1000)

# Create 200 sampling events with specified number of occasions and capture probabilities

B<-200

for(j in 1:B) {
  mydes <- generate.design.rm(mouse.lake, n.occ=3)
  mysurv <- setpars.survey.rm(clru.pop, mydes, pmin=0.1, pmax=0.5, improvement=0)
  mysamp <- generate.sample.rm(mysurv)
  myest<-point.est.rm(mysamp)
  est[j]<-myest$Nhat.grp
}

# Confidence bounds created from the quartiles of the 200 simulations

quantile(est[1:B], probs=c(0.025, 0.975))
hist(est[1:B],nclass=20, freq=F, main="Three occasion removal, N=100\n True N in blue, Mean estimate in red Empirical CI in green")
lines(c(100,100),c(0,16),lwd=2,col="blue")
lines(c(mean(est[1:B])),mean(est[1:B]),c(0,16),lty=2,lwd=2,col="red")
lines(c(quantile(est[1:B],probs=c(0.025)),quantile(est[1:B],probs=c(0.975))),c(0,0.01), lwd=2, col="green")
lines(c(quantile(est[1:B],probs=c(0.025)),quantile(est[1:B],probs=c(0.975))),c(0,0.01), lwd=2, col="green")
text(quantile(est[1:B],probs=c(0.025))-0.0005, round(quantile(est[1:B],probs=c(0.025)),0))
text(quantile(est[1:B],probs=c(0.975))-0.0005, round(quantile(est[1:B],probs=c(0.975)),0))

#
#----- Once again, for a different number of occasions
#
i <- 0
est <- rep(0,1000)

```

```
# Create 200 sampling events with specified number of occasions and capture probabilities
B<-200

for(j in i:B) {
  mydes <- generate.design.rm(mouse.lake, n.occ=4)
  mysurv <- setpars.survey.rm(clru.pop, mydes, pmin=0.1, pmax=0.5, improvement=0)
  mysamp <- generate.sample.rm(mysurv)
  myest<-point.est.rm(mysamp)
  est[[j]]<-myest$Nhat.grp
}

# Confidence bounds created from the quartiles of the 200 simulations

quantile(est[1:B], probs=c(0.025, 0.975))
hist(est[1:B],nclass=20, freq=F, main="Four occasion removal, N=100\n True N in blue, Mean estimate in red Empirical CI in green")
lines(c(100,100),c(0,16),lwd=2,col="blue")
lines(c(mean(est[1:B])),mean(est[1:B])),c(0,16),lty=2,lwd=2,col="red")
lines(c(quantile(est[1:B],probs=c(0.025)),quantile(est[1:B],probs=c(0.025))),c(0,0.01), lwd=2, col="green")
lines(c(quantile(est[1:B],probs=c(0.975)),quantile(est[1:B],probs=c(0.975))),c(0,0.01), lwd=2, col="green")
text(quantile(est[1:B],probs=c(0.025)), -0.0005, round(quantile(est[1:B],probs=c(0.025)),0))
text(quantile(est[1:B],probs=c(0.975)), -0.0005, round(quantile(est[1:B],probs=c(0.975)),0))

#
#----- Once again, for a different number of occasions
#
i <- 0
est <- rep(0,1000)

# Create 200 sampling events with specified number of occasions and capture probabilities
B<-200

for(j in i:B) {
  mydes <- generate.design.rm(mouse.lake, n.occ=5)
  mysurv <- setpars.survey.rm(clru.pop, mydes, pmin=0.1, pmax=0.5, improvement=0)
  mysamp <- generate.sample.rm(mysurv)
  myest<-point.est.rm(mysamp)
  est[[j]]<-myest$Nhat.grp
}

# Confidence bounds created from the quartiles of the 200 simulations

quantile(est[1:B], probs=c(0.025, 0.975))
hist(est[1:B],nclass=20, freq=F, main="Five occasion removal, N=100\n True N in blue, Mean estimate in red Empirical CI in green")
lines(c(100,100),c(0,16),lwd=2,col="blue")
lines(c(mean(est[1:B])),mean(est[1:B])),c(0,16),lty=2,lwd=2,col="red")
lines(c(quantile(est[1:B],probs=c(0.025)),quantile(est[1:B],probs=c(0.025))),c(0,0.01), lwd=2, col="green")
lines(c(quantile(est[1:B],probs=c(0.975)),quantile(est[1:B],probs=c(0.975))),c(0,0.01), lwd=2, col="green")
text(quantile(est[1:B],probs=c(0.025)), -0.0005, round(quantile(est[1:B],probs=c(0.025)),0))
text(quantile(est[1:B],probs=c(0.975)), -0.0005, round(quantile(est[1:B],probs=c(0.975)),0))
```